Empirical Analysis of Cost Progress Curves: An Investment Incentives Model Applied to Electronics Systems

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Outline

- Elements of the Investment Incentives Model(IIM)
- IIM Applied to Electronics Systems
- Summary

Elements of the Investment Incentives Model(IIM)

Developed by Dr. David Lee (LMI)

Basic Ideas

- **Model cost progress as the payoff of investments in producibility and production technology.**

- **Determine investment patterns as responses to economic incentives.**

Present Practice

- Ad hoc models of cost progress, e. g. $C_j = T_1 j^b$
- One curve shape parameter, b or, equivalently, slope $S = 2^b$
- For initial estimates, choose S by commodity, e. g. for a/c S ~ 80%, for electronics S ~ 90%

Choice of slope is subjective and causes much discussion!

Can We Do Better?

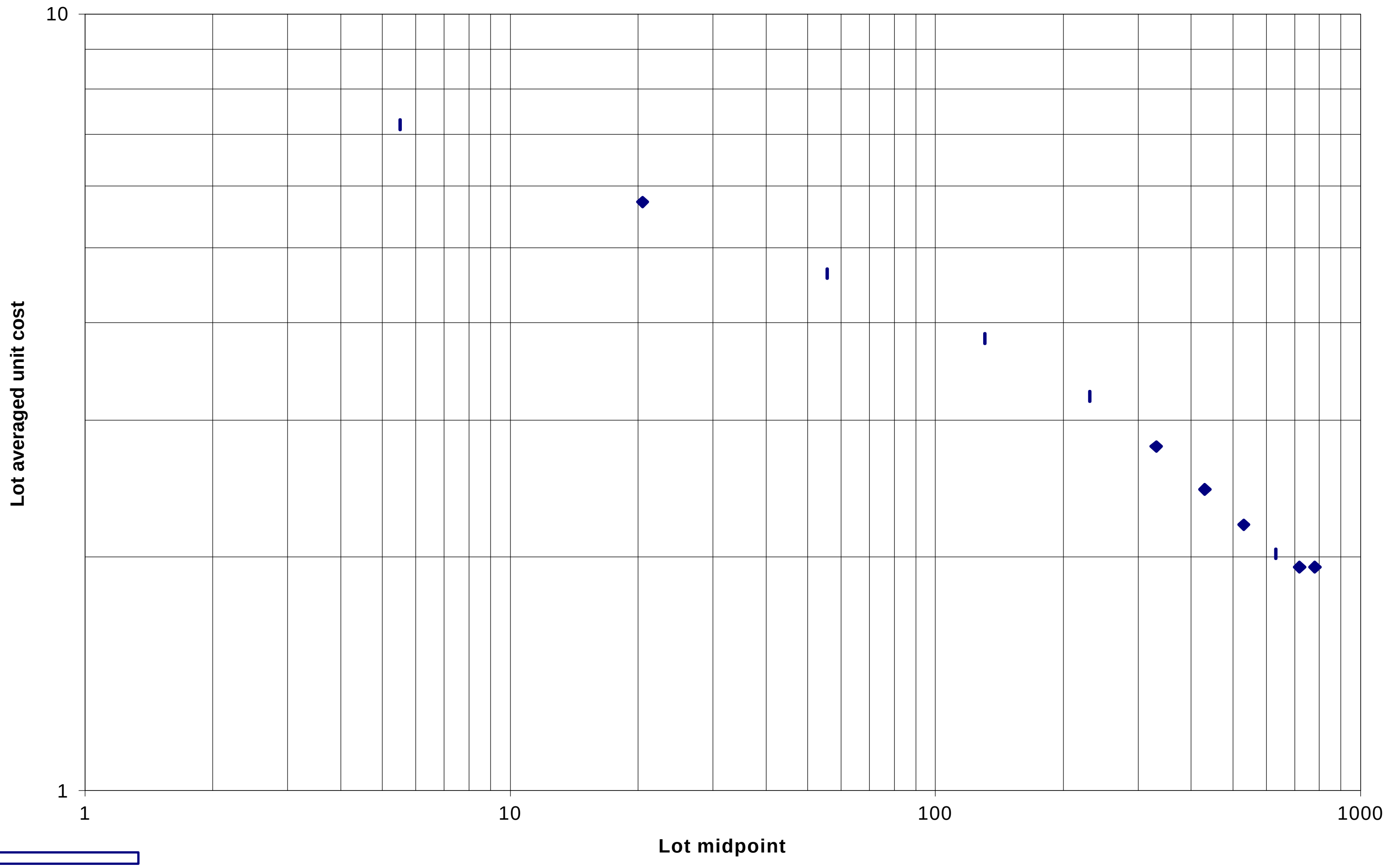
- Rational model of cost progress
- Relate features of cost progress model to features of product, plant, and, perhaps, industry
- Get shape of cost progress curves objectively, from data

From 32nd ADODCAS:

(paper by D. Lee, http:www.ra.pae.osd.mil/adodcas/32nd.htm)

- The idea that cost progress comes mostly from investments that either make items cheaper to produce, or make plants more efficient, leads to cost progress curves with three shape parameters.
- The parameters relate naturally to certain characteristics of the product, the production operation, and the business environment.
- One may determine the three shape parameters as functions of decision variables describing the product, the production operation, and the business environment.

Illustration of a Three Parameter Curve



The Three Shape Parameters

H is "Headroom"; measures excess of initial unit cost over lowest possible cost

S is "Sensitivity"; measures responsiveness of unit costs to investments

L is "Limit"; measures maximum per-period investment that can be absorbed

When these are fixed, a single multiplier, C*, determines the cost progress curve just as T_1 determines a Crawford or Wright curve once slope is fixed. Physically, C* is a theoretical lowest possible unit cost, in the way that T_1 is a theoretical first unit cost.

Qualitative Relations of Parameters to Product and Production Characteristics

Leads to larger H

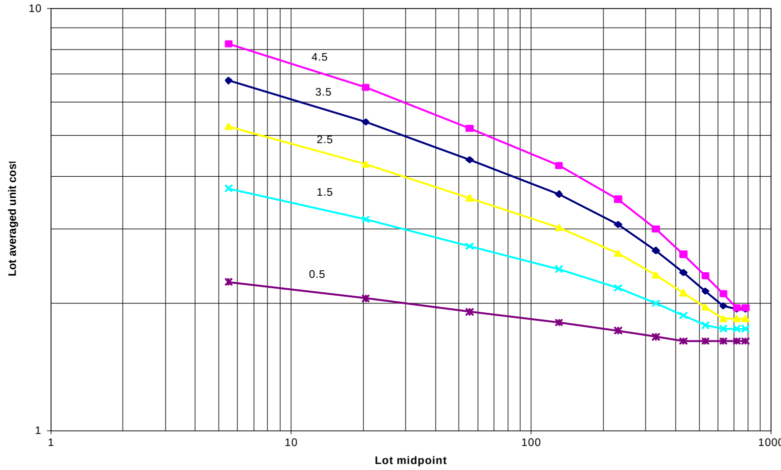
- Hurried EMD; great time pressure for item
- Firm has little experience producing similar items

Leads to smaller H

- Substantially automated plant

H is large when production begins at unit cost well above best unit cost

Effect of varying H



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Qualitative Relations of Parameters to Product and Production Characteristics

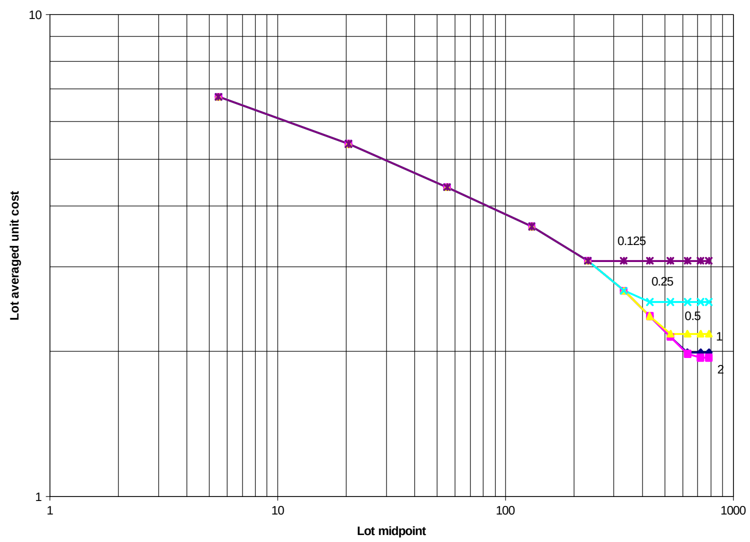
Leads to larger S

- Flexible, relatively inexpensive tooling
- Many steps in production

Leads to smaller S

- Extensive, expensive specialized tooling
- Substantially automated facility

Effect of varying S



S is large when lot cost is large compared to e-folding investment (the investment that reduces the difference between current unit cost and lowest possible unit cost, by a factor of 1/e).

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Qualitative Relations of Parameters to Product and Production Characteristics

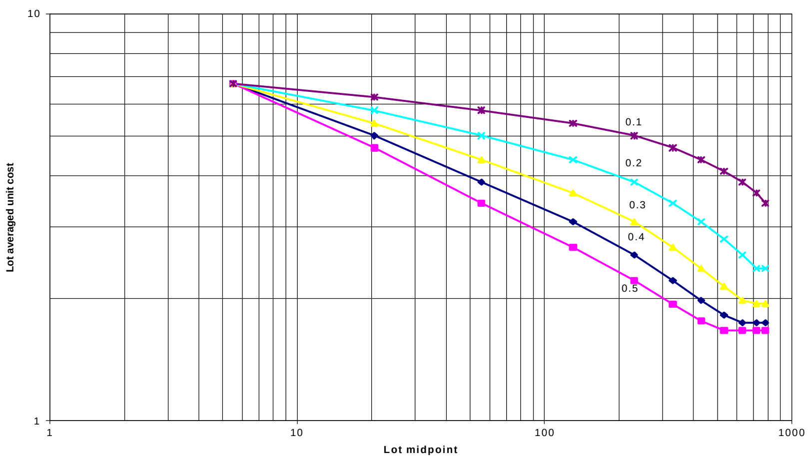
Tends to larger L

- Product dominant in firm
- Competition or threat thereof
- Great confidence in total quantity

Tends to smaller L

- Sole-source procurement
- Uncertain future

Effect of varying L



Three-Parameter Cost Progress Model

C_i is the unit cost of items in the i^{th} lot.

$$Ci = \begin{cases} C * \left[1 + He^{-iL}\right], 1 \le i < i^* \\ C * \left[1 + \dfrac{\overline{N}}{QR_{i^*}S}\right], i \ge i^* \end{cases}$$

$$i^* \equiv \max\left\{ i \mid \frac{1}{L}\ln\left(\frac{QR_i}{\overline{N}}SH\right) \ge i \right\}$$

This looks much more complicated that $C_j = T_1 j^b$! But in practice, it's just as easy to use, and one can determine shape parameters from data.

Determine the Three Shape Parameters as Functions of Descriptive Variables

- Three binary variables:
  - f_1: 1 => "complex" product
    0 => "simple" product
  - f_2: 1 => "automated" manufacturing
    0 => "non-automated" manufacturing
  - f_3: 1 => "competition" or threat thereof
    0 => "no competition" or threat thereof

Calibrating the IIM

Three translog functions determine H, S, and L given f_1, f_2 and f_3:

$$H = H_0 \beta_1^{f_1} \beta_2^{f_2} \beta_3^{f_3}; S = S_0 \gamma_1^{f_1} \gamma_2^{f_2} \gamma_3^{f_3}; \quad L = L_0 \eta_1^{f_1} \eta_2^{f_2} \eta_3^{f_3}$$

The 12 parameters H_0, β_1, β_2, β_3; S_0, γ_1, γ_2, γ_3; and L_0, η_1, η_2, η_3 determine these functions. "Calibrating" the IIM means assigning values to these 12 parameters.

With C* and rate exponent c for each of M systems, there are 12 + 2M adjustable parameters. To calibrate the model on a class of systems, choose the parameters to minimize a measure of the difference between model output and the data (such a measure is the sum of the squares of the differences between the model's output and the observed lot costs).

Once the model is calibrated, using it for new systems means evaluating f_1, f_2 and f_3, and determining C* (and a rate adjustment, if that is desired). Using the IIM given f_1, f_2 and f_3 is just like using a Wright or Crawford curve, given the slope.

Finding C* with available CERs

Many classical CERs yield values of T_1 for a Wright or Crawford curve.

To use these with a calibrated IIM, one may use the fact that the theoretical first unit cost is related to the theoretical lowest possible unit cost by

$$T_1 = C^*(1+H)$$

So, given a value of T_1 from a CER, values of f_1, f_2 and f_3, and a calibrated IIM, one may estimate C* as

$$C^* = \frac{T_1}{1+H(f_1, f_2, f_3)}$$

IIM Applied to Electronics Systems

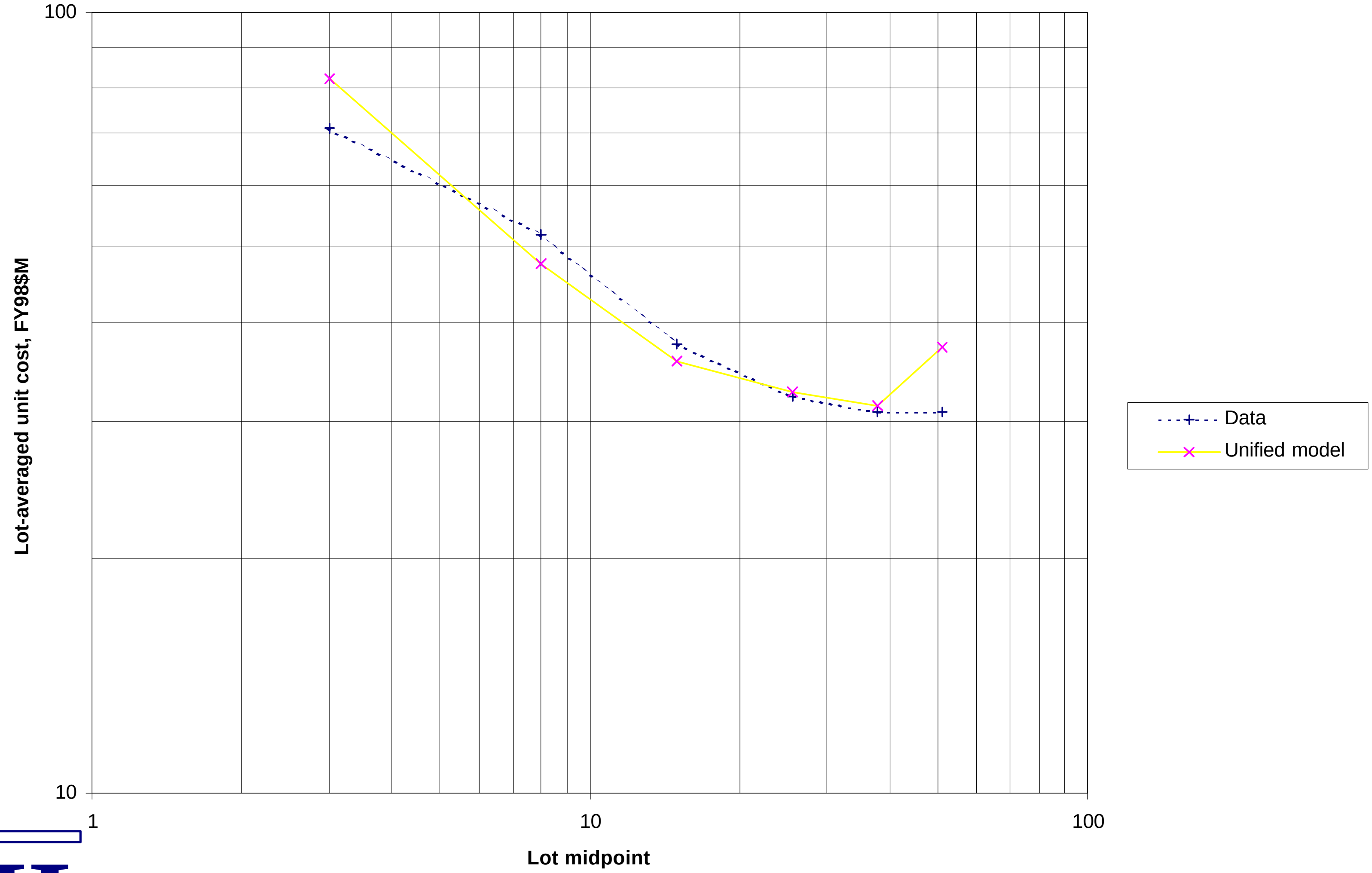
Original 8 Electronics Systems

- AN/MPQ-53: PATRIOT radar
- AN/APG-71: F-14D Radar
- ASR-9: FAA Airport Surveillance Radar
- AN/SQQ-89: Shipboard Anti-submarine Warfare Combat System
- AEGIS: Shipboard Anti-aircraft Warfare Combat System
- SINCGARS: Communications Radio (ITT)
- SINCGARS: Communications Radio(GD)
- PLGR: Handheld GPS Receiver

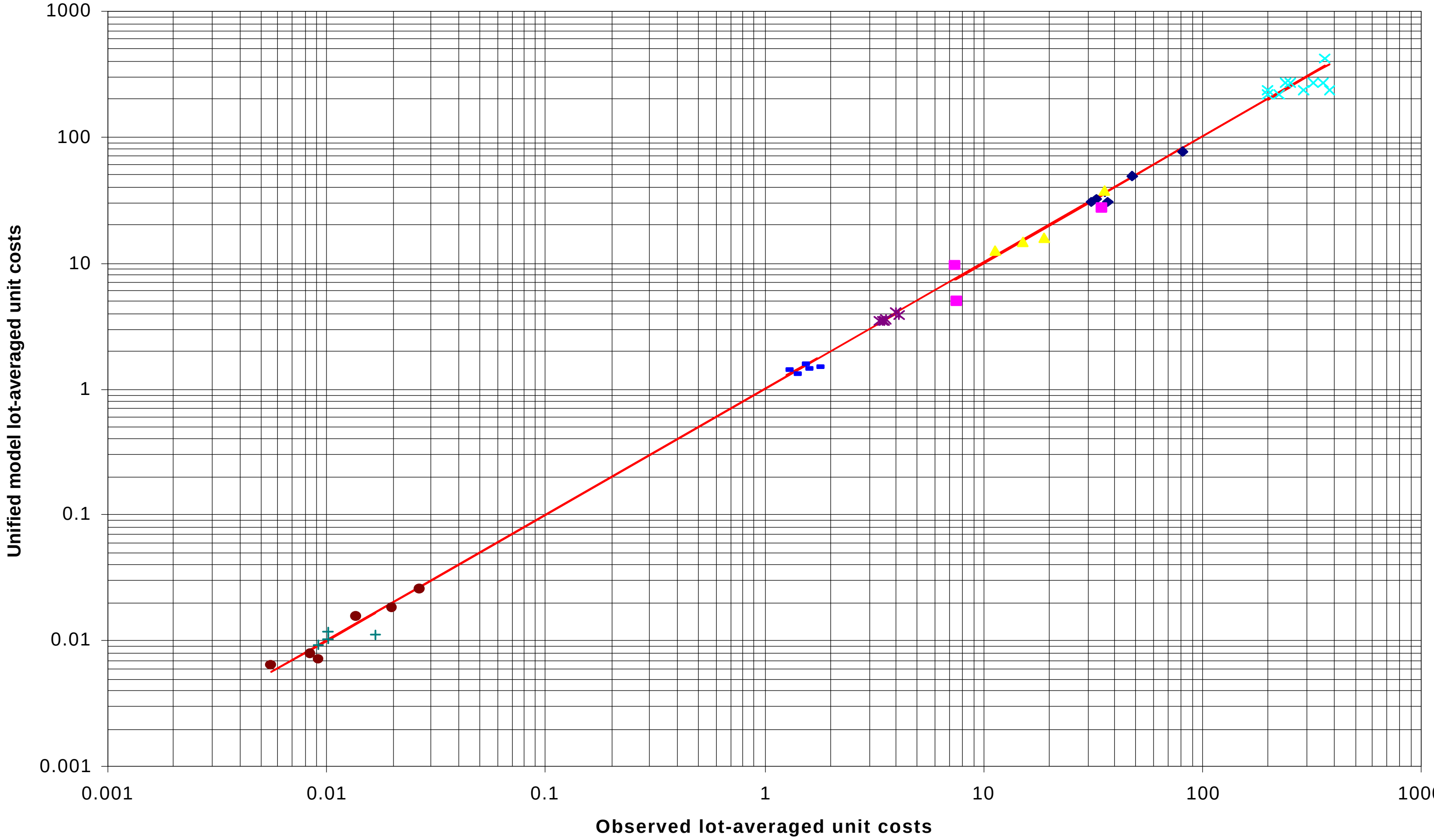
Resulting Parameters (Calibration on original 8 systems)

System	f_1	f_2	f_3	H	S	L
AN/MPQ-53	1	0	0	1.39	1387	9.74
AN/APG-71	1	0	0	1.39	1387	9.74
ASR-9	1	1	0	0.482	22.5	0.011
SQQ-89	1	0	1	0.027	48000	0.046
AEGIS	1	0	0	1.39	1387	9.74
SINCGARS-ITT	0	0	1	1.96	27.8	0.316
SINCGARS-GD	0	1	1	0.677	0.451	4x10
PLGR	0	1	0	34.5	0.013	0.078

Results for a Selected System



All Cases (Original 8 systems)



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Additional 9 Electronics Systems

- AN/URC-107(V): JTIDS Receiver/Transmitter Terminal: Rockwell Collins & GEC(Singer)
- AN/URC-107(V): JTID Display Processing Terminal: GEC(Singer)
- AN/ARN-151(V): GPS EPGI
- AN/ARC-190: VHF/UHF AM/FM Radio
- AN/ARC-182: VHF/UHF AM/FM Transceiver
- AN/ARC-210: VHF/UHF AM/FM Transceiver
- Target Acquisition Designation Sight(TADS): EO
- Pilot Night Vision Sensor (PNVS): EO

EO: Electro-Optics

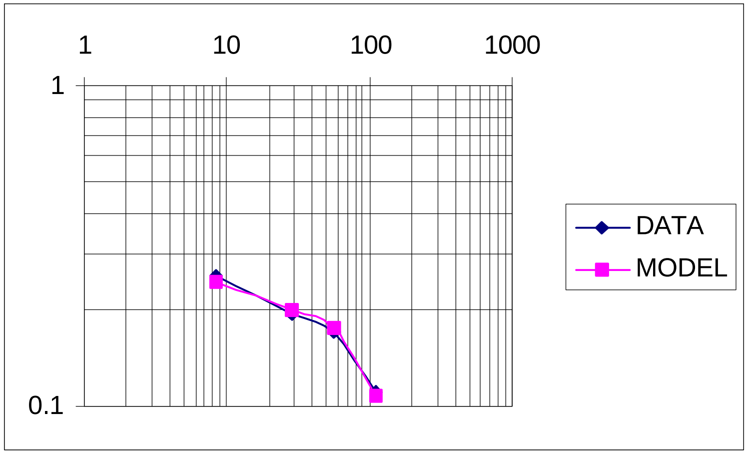
Resulting Parameters (Calibration on all 17 systems)

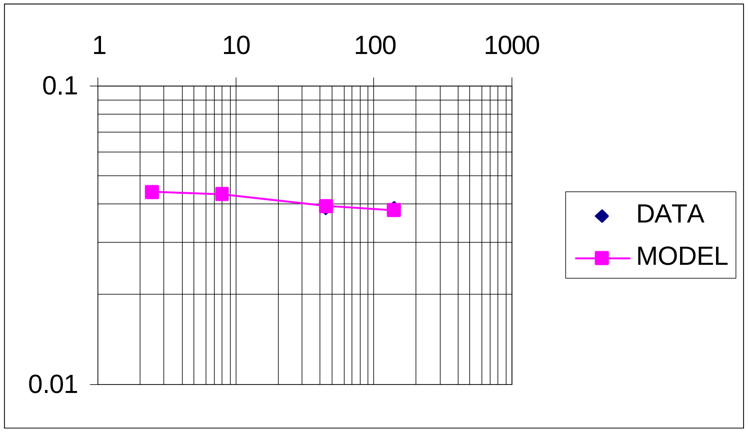
System	f_1	f_2	f_3		H	S	L
AN/MPQ-53	1	0	0		1.33	1439	9.74
AN/APG-71	1	0	0		1.33	1439	9.74
ASR-9	1	1	0		1.06	10.2	0.011
SQQ-89	1	0	1		0.076	17,200	0.015
AEGIS	1	0	0		1.33	1439	9.74
SINCGARS-ITT	0	0	1		5.68	9.56	0.106
SINCGARS-GD	0	1	1		4.51	0.068	0.0001
PLGR	0	1	0		79.3	0.006	0.082
AN/URC-107 R/T Terminal (RC)	1	1	1		0.060	122	$2x10^{-5}$
AN/URC-107 R/T Terminal (GEC)	1	1	1		0.060	122	$2x10^{-5}$
AN/URC-107 Display Terminal	1	1	1		0.060	122	$2x10^{-5}$
AN/ARN-151	1	1	1		0.060	122	$2x10^{-5}$
AN/ARC-190	1	0	1		0.076	17,200	0.015
AN/ARC-182	1	0	1		0.076	17,200	0.015
AN/ARC-210	0	0	1		5.68	9.56	0.106
TADS	1	0	1		0.076	17,200	0.015
PNVS	1	0	1		0.076	17,200	0.015

Applying IIM calibrated on original 8 systems to new systems

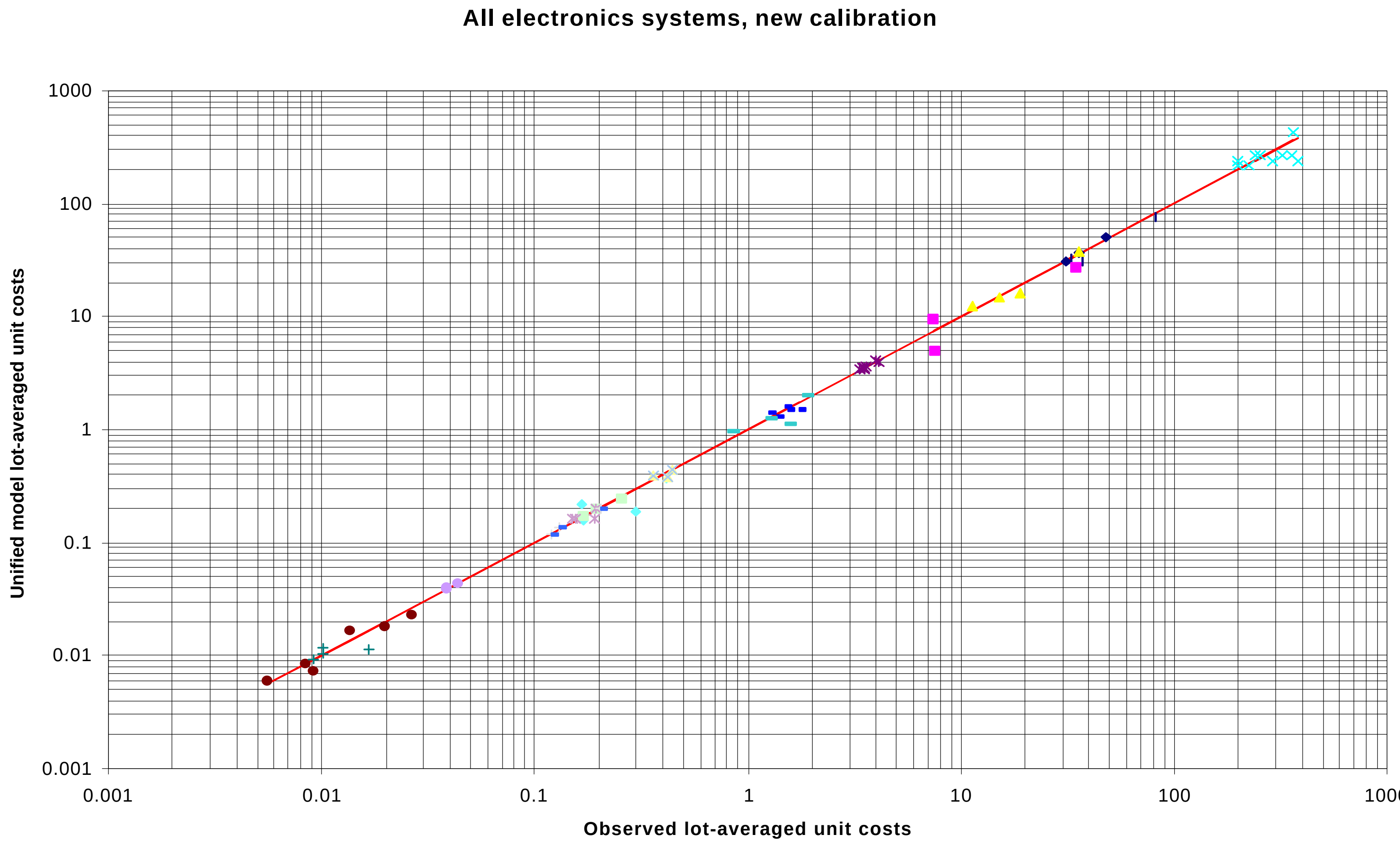
We were gratified to find that applying the IIM calibrated on the original 8 systems to the new systems gave good results, both in cases where there was significant cost progress (as in the upper chart at the right) and in cases where there was not (as in the lower chart). Both charts show lot-average unit costs versus lot midpoint.

This exercise gives an example of the way analysts can use a calibrated IIM.





All Cases
(Calibration on all 17 systems)



SUMMARY

How Can an Analyst Use the IIM?

- To forecast cost progress for a class of systems:
  - Calibrate the model (i. e. determine the 12 parameters of the functions giving H, S, and L as functions of f_1, f_2, and f_3) by fitting it to data for members of the class
  - Apply the resulting calibrated model by evaluating f_1, f_2, and f_3 and developing estimates for C* for other members of the class

This is like determining a “representative” slope for a class of systems, and then using that slope for other similar systems.

How Can an Analyst Use the IIM?

- To forecast cost progress for a member of a class on which the model has been calibrated:
  - Determine values of f_1, f_2, and f_3
  - Determine C* (and, if desired, a rate adjustment model) from a CER, or from data for the system

This is like using a "representative" slope for a class of systems

This Presentation Has Examples of Both Ways to Use the IIM

- Applying the model calibrated on the original 8 systems, to forecast cost progress for the second set of 9 systems, is an example of using a calibrated IIM.
- Calibrating the model on the new set of 17 systems is, of course, another example of calibration.

Conclusions

- The investment incentives model (IIM) is an encouraging alternative to the traditional model for electronics systems as a commodity class.
- Generally good results of applying IIM to new electronics programs and to tactical missile programs(preliminary results not presented)suggests encouraging robustness, and yet a more encouraging possibility of cross-commodity applicability.